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Economic welfare impacts from renewable energy consumption: The China experience

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A B S T R A C T

Over the last years renewable energy sources have increased their share on electricity generation of China due to environmental and security of supply concerns. In this work author assesses the role of both the amount and share of renewable energy consumption in economic welfare using Cobb–Douglas type production functions. This assessment is carried out by multivariate OLS and SPSS software for China from 1978 to 2008. Results indicate that a 1% increase in renewable energy consumption (REC) increases real GDP by 0.120%, GDP per capita by 0.162%, per capita annual income of rural households by 0.444%, and per capita annual income of urban households by 0.368% respectively; the impact of renewable energy consumption share (SREC) on economic welfare is insignificant, and an increasing share of REC negatively affects economic welfare growth to a certain extent. In this paper, the cost, structural demand, accounting mechanism and policy reasons of renewable energy development are interpreted. Marginal effects analysis show that the shape of sound and robust renewable energy institutions and policies would matter for increasing the standards of economic welfare in the context of speeding up renewable energy development and increasing share of renewable energy consumption, especially the goal-oriented policy refinement should be addressed efficiently in improvement households income while increasing share of renewable energy consumption.

Contents

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1. Introduction

1.1. Development of renewable energy in China

Development of renewable energy resources in China can be traced to the 1950s, shortly after the foundation of the People's Republic of China. From 1958 to 1960, in total 41 tidal power stations were built in coastal provinces such as Fujian, Guangdong and Zhejiang. In 1971 the photovoltaic (PV) panels were installed on Dongfanghong-2 Manmade Satellite2. However, pressures of energy shortage and energy related environmental pollution at that time were not as significant as they are today. Development of renewable energy in China remained at experiment level with immature technologies and limited scales for about 30 years [1,2].

China, following some advanced countries, started its nationwide development of renewable energy resources from the end of the 1970s and especially after the reform and opening-up in 1978. Rising concern of environmental protection and the two oil crises in 1973 and 1979 stimulated China's determination to reduce its reliance on coal and imported oil. From 1978 to 2000, the Chinese government involved renewable energy development into its Five-year Plan and national laws such as the *China Electric Power Act* in 1995 and the *China Energy Saving Law* in 1998. As a result, renewable energy consumption in China increased steadily. About 7 million household biogas pools and more than 70,000 centralized biogas stations were constructed in China in this period. Two single crystalline silicon solar cell production lines were introduced in the mid 1980s. In 1989 China built its first grid-connected wind farm in Xinjiang [2–5].

From the beginning of the 21st century, the Chinese government used market incentives, in addition to command and control management and direct subsidies, to stimulate renewable energy production. The Chinese government started numerous renewable energy demonstration projects such as Integrated Rural Energy Development Program with Rural Economic Development, the China Brightness Program and the China Renewable Energy Scale-up Program. Activation of the *Renewable Energy Law* in 2006 provided legal authority and created a new era for renewable energy development in China. International cooperation via Clean Production Mechanism (CDM) transferred both financial and technical resources from developed countries to China. These policies and programs resulted in great development of renewable energy utilization, especially small hydro, wind power, solar thermal and bio-energy, in China [2].

In 2008, the amount of renewable energy consumption in China equaled to about 239 Mtce, which accounted for 8.4% of China's total primary energy consumption (Fig. 1). By the end of 2008,

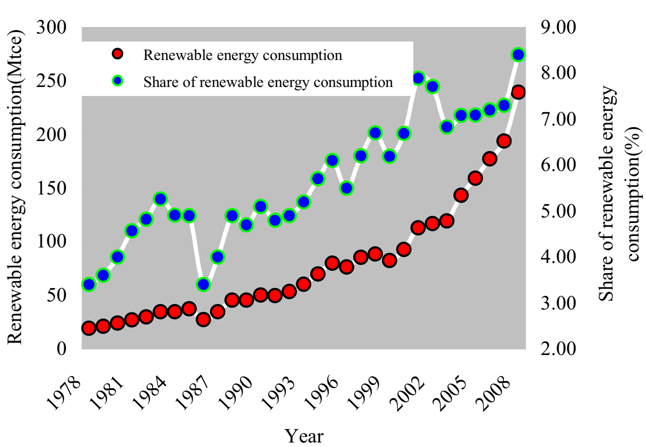

Fig. 1. Renewable energy consumption for China from 1978 to 2008.

the installed capacity of hydropower is 145.26 GW [6]. China had the largest small hydropower capacity (60 GW), the largest solar water heater installation (140 million m^2 collector areas), the third largest bio-ethanol production (1.9 billion L), and the fourth largest wind power generation capacity (12 GW) in the world. All these data prove the fact that China is going to overtake developed countries to be a leading producer and "a pioneer leading the way" in developing renewable energy resources [2,7].

Renewable energy is in a rapid development stage in China, and some technologies are in commercialization or near commercialization and have large development potential from resource, technology and industry points. Renewable energy has begun to play a key strategic role in the energy structure. According to the national target, renewable energy consumption will represent 15.5–19.7% of the total primary energy in China in 2020. It is expected that it will reach 26.4–43.0% in 2050 and renewable energy will be important substitute energy at that time [8,9].

1.2. Literature survey

Modeling the relationship between energy consumption and income in emerging economies has been a very active area of research [10–33]. These studies typically concerned the effects of energy conservation policies on economic growth. Some of them found that energy consumption contributed to economic growth both directly and/or indirectly, others that economic growth determined energy consumption, others that energy consumption and real gross domestic production (GDP) were interdependent and that there was bidirectional causality among them or even that there was no causality relationship among variables [34].

Renewable energy as a means to mitigate the environmental impact of carbon emissions while satisfying the energy needs for economic growth, thus, in recent years, increasing attention being paid to renewable energy, as a result research on the relationship between renewable energy consumption and economic growth has emerged in the literature. Nonetheless, this branch is not as developed as the previous one and the number of published researches is rather small. In a recent study, Domac et al. [35] argued that bio-energy should help increase the macroeconomic efficiency through the creation of employment and other economic gains. Later, Awerbuch and Sauter [36] defended that renewable energy sources had a positive effect on economic growth by reducing the negative effects of oil prices volatility. Furthermore, they contributed to energy supply security. These effects have to be considered when fully assessing the comparative costs of renewable energy and fossil fuels. Ewing et al. [37] used the generalized forecast error variance decomposition analysis to investigate the effect of disaggregated energy consumption (coal, oil, natural gas, hydro power, wind power, solar power, wood and waste) on industrial output in the USA. The authors found that non-renewable energy shocks (coal, gas and oil) had more impact on output variation than other energy sources. Even so, several renewable sources also exhibited considerable explanatory power. In their 2007 study, Chien and Hu [38] noted that renewable energy source significantly increased the technical efficiency (TE) of the economies studies. They used the data envelopment analyzes (DEA) method to estimate the TE for 45 OECD and non-OECD economies for 2001–2002. Similarly, these authors [39] also studied the effects of renewable energy consumption on GDP for 116 economies in 2003 through the Structural Equation Modeling (SEM) approach. They decomposed GDP by the "expenditure approach" and concluded that renewable energy consumption had a positive indirect effect on GDP through the increasing in capital formation. However, the authors found that renewable energy use did not improve the trade balance having no import substitution effect. Sari et al. [40] used the autoregressive distributed lag (ARDL) approach to examine the

relationship between disaggregated energy consumption (coal, fossil fuels, natural gas, hydro, solar and wind power, wood and waste), industrial output and employment for the USA. They found that, in the long-run, industrial production and employment were the key determinants of fossil fuel, hydro, solar, waste and wind energy consumption, but did not have a significant impact on natural gas and wood energy consumption. Chang et al. [41] employed a panel threshold regression (PTR) model to investigate the influence of energy prices on renewable energy development under different economic growth rates for the OECD countries over the period 1997–2006. They claimed there was no direct and simple relationship between GDP and the contribution of renewable energy to energy supply. These authors concluded that the level of economic growth of a country influenced the use of renewable energy as a way to respond to oil price shocks. High-economic growth countries used renewable energy to minimize the effects of adverse price shock, but low-economic growth countries were unable to do so. Therefore, the first countries exhibited a substitution effect towards renewable energy to avoid the negative relationship between oil prices and GDP. In the same year, Sadorsky [42] used a panel empirical model to estimate renewable energy consumption for the G7 countries. The multivariate model included renewable energy consumption per capita (geothermal, wind and solar power, waste and wood), real GDP per capita, CO_2 emissions per capita and oil prices. The author found that, in the long-run, real GDP per capita and CO_2 per capita were the main drivers of renewable energy consumption per capita. Indeed, a 1% increase in GDP leads to 8.44% increase in renewable energy consumption while a 1% increase in CO_2 emissions lead to a 5.23% increase. Sadorsky [43] also studied the relationship between renewable energy consumption and income estimating two empirical models for a panel of 18 emerging economies for the period 1994–2003. The study used panel cointegration techniques and a vector error correction model. The author found that increases in real GDP had a positive and statistically significant effect on renewable energy consumption per capita. However, there was not a bidirectional feedback between the two variables. Payne [26], Bowden and Payne [44] compared the causal relationship between renewable and non-renewable energy consumption and real GDP for the USA using annual data from 1949 to 2006. The author used Toda–Yamamoto causality tests in a multivariate framework and found no Granger causality between renewable and nonrenewable energy consumption and real GDP. Finally, Apergis and Payne [45,46] studied the relationship between renewable energy consumption and economic growth for 20 OECD countries over the period 1985–2005 and 13 countries within Eurasia over the period 1992–2007 within a multivariate framework. The authors examined a long-run equilibrium relationship between real GDP and renewable energy. In concrete, a 1% increase in renewable energy consumption increased real GDP by 0.76%. In addition, Silva's [34] result indicate that for USA, Denmark, Portugal and Spain four countries in the sample, except for the USA, the increasing renewable energy consumption share had economic costs in terms of GDP per capita. As expected, there was also an evident decrease of CO_2 emissions per capita by used the Structural Vector Autoregressive (SVAR) model along the period 1960–2004.

An issue related to the use of renewable energy in the design and implementation of a sustainable energy strategy is its impact on economic growth. This study will address this issue by examining the causal relationship between renewable energy consumption and economic welfare growth within a Cobb–Douglas production model framework for China. However, this study departs from previous studies. Main objectives of this study are: (1) to extend this line of research from national economic welfare (GDP, GDP per capita) to both national and individual economic welfare (per capita income of rural and urban households) in order to determine the degree to which the total renewable energy consumption and the share of renewable energy consumption influence economic welfare; (2) to project the affecting scenarios of renewable energy consumption on economic welfare; (3) to gain further understanding of the relationship between both the amount and share of renewable energy consumption and economic welfare output in China. As China has been the fastest-growing major nation for the last three decades with an average annual GDP growth rate of nearly 9.8% [47]. The thrust behind China's rapid economic growth is provided by large injections of energy, derived primarily from coal (nearly 70% of the total energy consumption) [48]. The total energy consumption of China increased about 465% from 1978 to 2007 [47]. China is by far the biggest contributor to incremental emissions, overtaking the United States as the world's biggest emitter in 2006, where coal-burning holds dominant place [49]. Today, all countries around the world are concerned with energy security issues and global warming and increasing the usage of renewable energy offers one way to address both of these problems. In response to the increased demand for energy coming from China and the greater role that renewable energy is expected to play in meeting some of this increased demand, it is useful to gain a better understanding of the relationship between renewable energy consumption and economic welfare in China.

Section 2 presents the methodology and data, results and discussion, and concluding remarks given in Sections 3 and 4 respectively.

2. Methodology and dataset

2.1. Economic welfare and indicators

Economic welfare is the level of prosperity and quality of living standards in an economy. Economic can be measured through a variety of factors such as gross domestic product (GDP) and other indicators which reflect welfare of the population. It is also explained as the welfare of an individual or group which comes from the purchase and consumption of goods and services [50]. GDP is the main economic growth indicator and is used in most the studies as a proxy of income [43]. Furthermore, the use of GDP instead of GNP seems appropriated in this study. Therefore, in this context, we include GDP, GDP per capita, per capita annual income of rural households, and per capita annual income of urban households as pillow indicators to mirror national and individual two-dimensions of economic welfare.

In this empirical work, author tries to identify the role of renewable energy consumption in economic welfare (economic well-being). It is applied a multivariate ordinary least squares (OLS) model and SPSS software to perform the necessary calculation. Thus, economic welfare e.g. GDP, GDP per capita, per capita annual income of rural households, and per capita annual income of urban households are identified as our dependent variables (output variables). And the amount and share of renewable energy consumption are as our independent variables (input variables).

2.2. Cobb–Douglas production function

In economics, the Cobb–Douglas functional form of production functions is widely used to represent the relationship of an output to inputs. It was proposed by Knut Wicksell (1851–1926), and tested against statistical evidence by Cobb and Douglas in 1928 [51]. The general function they used to model production was of the form:

$$Q = AL^{\alpha}K^{\beta}$$

where Q = total production (the monetary value of all goods produced in a year); L = labor input (the total number of person – hours worked in a year); K = capital input (the monetary worth of all

machinery, equipment, and buildings); A = total factor productivity; α, β are the output elasticities of labor and capital, respectively. These values are constants determined by available technology.

A more important problem with the original specification of the functional relationship is the omission of technical change. The need to take account of technical change in estimation was noted by Handsaker and Douglas [52] and Williams [53]. In order to quantify the impacts of renewable energy consumption on economic welfare, new variables are added: the logarithm of total consumption of renewable energy, share of renewable energy consumption, per capita R&D expenditure. It was selected gross capital formation, the number of employees and per capita R&D expenditure as proxy variables for capita, labor and technological progress respectively. Thus, the log form of a Cobb–Douglas is specified as:

$$\ln\ Y_i = \varphi + \alpha\ \ln\ \mathrm{REC} + \beta\ \ln\ \mathrm{SREC} + \gamma\ \ln\ K + \delta\ \ln\ L + \lambda\ \ln\ T + \mu$$

where Y_i (i = 1, 2, 3, 4) are the GDP, per capita GDP, per capita annual income of rural and urban households respectively, REC is total renewable energy consumption, SREC is the share of renewable energy consumption, K is the gross capital formation, as a proxy for capital stock, L is the total number of employees which is considered as a proxy for labor variable, T is per capita R&D expenditure, as a proxy for technological progress, in represents a natural logarithm, and $\varphi, \alpha, \beta, \gamma, \delta, \lambda$ are unknown parameters to be estimated, μ is an error term.

The empirical assessment is based on above Cobb–Douglas type economic well-being production functions. These are very simple and widely used functions that allow for a simple and intuitive interpretation of coefficients as constant elasticity of each factor of production.

2.3. Data for model estimation

The dataset was assembled for China from 1978 to 2008, mainly with respect to economic welfare and renewable energy indicators, e.g. data of GDP, GDP per capita, per capita annual income of rural and urban households, the number of employee, and annual R&D expenditure per employee, share of renewable energy consumption from Chinese Statistical Yearbook (1978–2008), Chinese Science & Technology Statistical Yearbook (1990–2008). The indicators, not available from any consistent sources, like gross capital formation, is from Macrochina Database, irregular statistical reports, and the projected goals for the amount and share of renewable energy consumption are from the strategy research group of Chinese renewable energy development, etc.

3. Results and discussion

3.1. Renewable energy use and economic welfare

It is noticeable a positive correlation between GDP, GDP per capita, per capita annual income of rural households, per capita annual income of urban households and total renewable energy consumption (Fig. 2). The high correlation between these variables also provides an expectation that renewable energy consumption be an interesting variable to explain economic welfare variable.

In overall tendency, despite its different magnitudes, the strong correlation observed between GDP, GDP per capita, per capita annual income of rural households, per capita annual income of urban households and the share of renewable energy consumption might show that higher economic welfare is accompanied by higher share in renewable energy use throughout China (Fig. 3). However, an indicator-by-indicator assessment shows that increases in per capita annual income of rural and urban households are not closely related with the share of renewable energy consumption increases, but may rather be related with structural characteristics of rural and urban households' expenditure or policy of renewable energy consumption.

3.2. Models estimation

On basis of the data of the analyzed period and above method, a Cobb–Douglas type economic welfare functions are estimated respectively as follows.

3.2.1. GDP production function

$$\ln\ Y_1 = 0.120\ \ln\ \mathrm{REC} + 0.031\ \ln\ \mathrm{SREC} + 0.728\ \ln\ K + 0.029\ \ln\ L + 0.131\ \ln\ T + 2.574 \quad (1)$$

where Y_1 is the GDP in real term.

3.2.2. GDP per capita function

$$\ln\ Y_2 = 0.162\ \ln\ \mathrm{REC} + 0.009\ \ln\ \mathrm{SREC} + 0.734\ \ln\ K - 0.006\ \ln\ L + 0.136\ \ln\ T + 3.641 \quad (2)$$

where Y_2 is the GDP per capita.

3.2.3. Household income function

Per capita annual income of rural households is estimated as a function of renewable energy consumption, labor force and capital input:

$$\ln\ Y_3 = 0.444\ \ln\ \mathrm{REC} - 0.064\ \ln\ \mathrm{SREC} + 0.567\ \ln\ K - 0.097\ \ln\ L + 0.174\ \ln\ T + 5.894 \quad (3)$$

where Y_3 is per capita annual income of rural households.

On the other hand, per capita annual income of urban households is also estimated as a function of renewable energy consumption, labor force and capital input:

$$\ln\ Y_4 = 0.368\ \ln\ \mathrm{REC} - 0.203\ \ln\ \mathrm{SREC} + 0.637\ \ln\ K + 0.012\ \ln\ L + 0.220\ \ln\ T + 3.513 \quad (4)$$

where Y_4 is per capita annual income of urban households.

3.2.4. Statistical test of models

In Table 1 the obtained results for mentioned above models are presented. The results in Table 1 show that the significant variables were gross capital formation, per capita R&D expenditure and renewable energy consumption—all assuming expected signs. In these variables parameters, gross capital formation and per capita R&D expenditure are statistically significant to the 1% level, and renewable energy consumption to the 5–1% level. Analyzing the sample on the basis of Cobb–Douglas production function through time, it is observed that the number of employees, share of renewable energy consumption is not significant at 10–1% except β in model (4). In particular, the mean output elasticity of labor is insignificant in all models. Although statistically insignificant, this result points at the labor abundance in China and the low marginal productivity of labor. The greatest elasticity observed is that of gross capital formation. This indicates the intense relationship that exists between economic welfare production and gross capital formation. The variable of total renewable energy consumption reveals the second major elasticity, confirming the importance of renewable energy consumption to both national and individual economic welfare. As expected, assuming positive and inferior elasticity in relation to the other relevant factors, the technological progress (per capita R&D expenditure) contributes for economic well-being at national and individual level (Table 1).

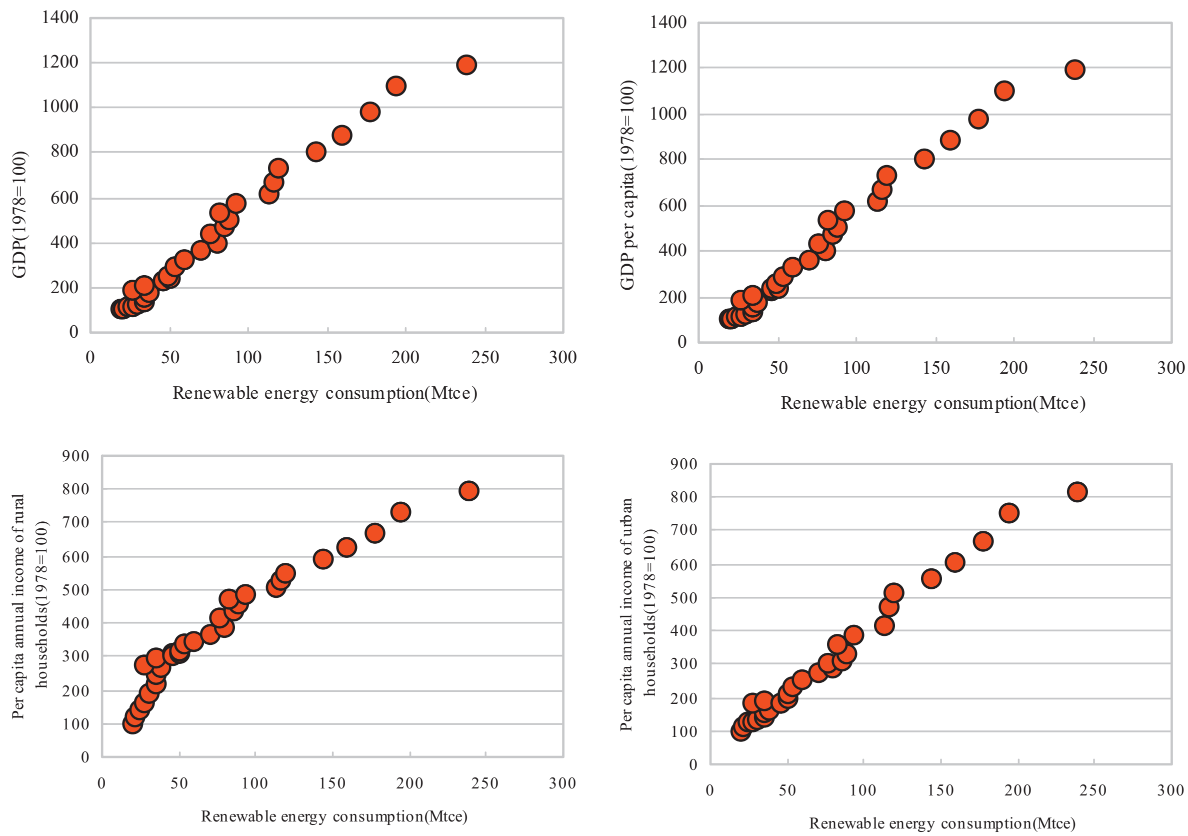

Fig. 2. Economic welfare vs renewable energy consumption for China from 1978 to 2008.

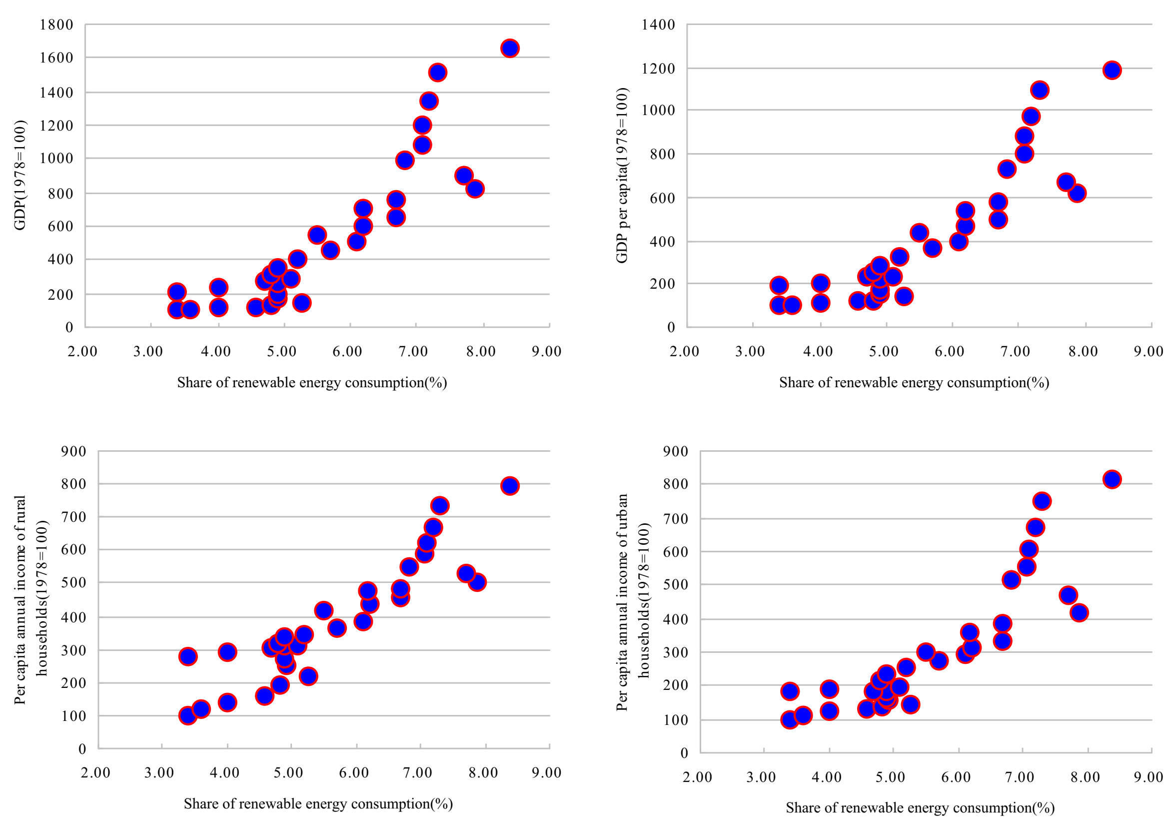

Fig. 3. Economic welfare vs share of renewable energy consumption for China from 1978 to 2008.

Table 1
Multivariate OLS results.

Independent variables and parameters		Dependent variable (economic welfare)			
		GDP (Y_1)	GDP per capita (Y_2)	Per capita annual income of rural households (Y_3)	Per capita annual income of urban households (Y_4)
Renewable energy consumption (REC)	α	0.120* (0.077)	0.162** (0.070)	0.444*** (0.082)	0.368*** (0.102)
Share of renewable energy consumption (SREC)	β	0.031 (0.098)	0.009 (0.090)	−0.064 (0.105)	−0.203*** (0.131)
Gross capital formation (K)	γ	0.728*** (0.032)	0.734*** (0.029)	0.567*** (0.034)	0.637*** (0.043)
Number of employees (L)	δ	0.029 (0.153)	−0.006 (0.140)	−0.097 (0.164)	0.012 (0.204)
Per capita R&D expenditure (T)	λ	0.131*** (0.033)	0.136*** (0.030)	0.174*** (0.035)	0.220*** (0.044)
Intercept	φ	2.574*** (0.890)	3.641*** (0.816)	5.894*** (0.951)	3.513*** (1.185)
R^2		0.998	0.998	0.992	0.994
R^2 (adjusted)		0.998	0.998	0.989	0.993
F		1881.353***	1802.603***	399.497***	612.894***
$P(F<c)$		0.000	0.000	0.000	0.000

* Significance: 10% level.
** Significance: 5% level.
*** Significance: 1% level.

3.3. Impact of REC on economic welfare

According to "China Renewable Energy Development Strategy Research" series report – integrated volume, complied by Chinese Academy of Engineering in 2008 [8], the strategic position of renewable energy in China will act different role in near future and medium and long term [9]:

Near future (*around 2010*): Non-hydro renewable energy is meant to be supplementary, amount to 2% of the total energy demand. With hydro energy on the account, renewable energy will supply about 0.29 billion TCE, nearly 10% of the national total energy demand.

Medium-term (*around 2020*): Non-hydro energy will turn into a substitute sector, about 5–10% of the national total demand. It will go up to 0.54–0.69 billion TCE when hydro energy is included, satisfying about 15.5–19.7% of the national total energy demand.

Long-term (*around 2030*): Non-hydro renewable energy will become one of the mainstream energy supplies, about 10–19% of the national total energy demand. With the share of hydro-energy included, renewable energy will offer 0.86∼1.26 billion TCE, meeting about 20–30% of the national total energy demand.

Far future (*around 2050*): Renewable energies should strategically be one of the leading energy supplies, delivering 0.88–1.71 billion TCE, reaching to 17–34% share of the national total demand or even higher. The supplies reach about 1.32–2.15 billion TCE when the contribution of hydro energy is added, and providing 26–43% of the national total energy demand.

On the basis of the objective and output elasticity of REC mentioned above, summary statistics for the total renewable energy input and economic welfare output quantities are given in Table 2. From this table we note that the GDP, GDP per capita, per capita annual income of rural households, per capita annual income of urban households shall keep increasing accompanied by renewable energy consumption increase. However, the positive effects of per capita annual incomes for rural and urban households are higher than that of GDP and GDP per capita. This is evident from the fact that the means of output elasticity for per capita annual incomes for rural and urban households are more than twice as large for GDP and GDP per capita.

Table 1 reveals that a 1% increase in REC increases real GDP by 0.12%, GDP per capita by 0.162%, per capita annual income of rural households by 0.444%, and per capita annual income of urban households by 0.368% respectively. In light of above elasticity estimate, this will generate 9.29–15.06% advantage in real GDP, 12.55–20.33% advantage in GDP per capita, 34.39–55.72% advantage in per capita annual income of rural households, and 28.50–46.18% advantage in per capita annual income of urban households respectively in 2020; this also will generate 39.76–72.31% advantage in real GDP, 53.68–97.62% advantage in GDP per capita, 147.13–267.56% advantage in per capita annual income of rural households, and 168.25–221.76% advantage in per capita annual income of urban households respectively in 2050 (Table 2).

3.4. Impact of SREC on economic welfare

The impact analysis of SREC on economic welfare provides interesting insights. In Table 2, these variables parameters, GDP and GDP per capita are statistically insignificant. For per capita annual income of rural and urban households, the sign on the coefficients is negative, with the estimate being statistically significant for per capita annual income of urban households. In other words, if output elasticity is negative, the inefficiency of SREC (input) will be increasing over time. Given parameters estimate for SREC, the positive sign of output elasticity of GDP (0.031), output elasticity of GDP per capita (0.009) indicates that the positive effects occurrence of SREC on GDP and GDP per capita although these effects are very slightly. And the negative sign of output elasticity of per capita households' income (−0.064 and −0.203) shows that an increasing share of REC negatively affects economic welfare growth. Thus, taking into account the estimated parameters and statistical tests, clearly these results make no sense in the context of estimating a production function. Indeed, a variety of economic, financial, technical and administrative barriers may block, hinder or else at the least delay renewable energy deployment. It exist certain facts in China even in many developing countries, for main reasons result in negative effect of economic welfare growth.

Cost effects: in strategy view, renewable energy is assuming an increased importance across China due to security of supply issues as well as environmental and dependency concerns. However, a variety of policies and institutional barriers may affect economic welfare at national and individual level. Cost effects are often mentioned as an important mechanism in how REC policies influence the economy. The primary cost factors in the general economic

Table 2
The impact of REC on economic welfare.

	Base year (2009)	Scenarios and projections								
		2020			2030			2050		
		Low	Middle	High	Low	Middle	High	Low	Middle	High
Total energy consumption (100 Mtce)	31		35			42			50	
REC (100 Mtce)	3.06	5.43	6.16	6.90	8.61	10.29	12.60	13.20	17.05	21.50
SREC (%)	9.9	15.5	17.6	19.7	20.5	24.5	30.0	26.4	34.1	43.0
GDP growth (%)		9.29	12.16	15.06	21.76	28.35	37.41	39.76	54.86	72.31
GDP per capita growth (%)		12.55	16.41	20.33	29.38	38.28	50.51	53.68	74.06	97.62
Per capita annual income growth for rural households (%)		34.39	44.98	55.72	80.53	104.91	138.42	147.13	202.99	267.56
Per capita annual income growth for urban households (%)		28.50	37.28	46.18	66.75	86.95	114.73	121.95	168.25	221.76

discussion are the costs of labor and capital. With regard to REC, another cost factor is the higher cost of supplying REC compared to conventional forms of energy. This cost increase triggers various supply-side effects. It leads to a reduction of the output due to higher costs and furthermore, to substitutions in favor of other production factors. If the cost burden falls on private households, i.e. if they have to pay higher prices for energy; if the cost burden is to borne by the public budget, the government will have to reduce other expenditure, or alternatively, the government will raise tax revenues in other areas and thus reduce the available budget of consumers or producers, and further affects national or individual income.

Structural demand effects: in addition to changes in costs or prices, an increase in REC also leads to structural changes in the economic welfare. Implementing a REC policy requires additional investments to increase SREC. At the same time, there is a drop in demand for both conventional energy carriers and conventional energy supply investments. In general, however, the costs for REC are assumed to be higher that the capital and running costs for the conventional energy supply. Typically, a substantial share of the higher cost is transferred to the consumers. According to Cai and Jiang's [54] survey, from village to city in central China, the patterns of energy consumption vary substantially. The energy choices shift from free biomass to cleaner commercial sources like LPG, electricity and natural gas. The same evidence also shows that with the rapid economic development in rural areas of Huantai County in the past 16 years, the ratio of commercial to household energy consumption increased 17.75%. Although coal consumption was much higher than any other energy type and accounted for 64.92% of all household energy consumption, and the consumptions of renewable energy increased dramatically for recreational activities and cooking [55]. As a result of these shifts, results in the expansion of households' renewable energy expenditure, and further affects individual income. On the other hand, China is a so-called "fossil-fueled civilization" as its energy system demonstrates unsustainable patterns of development, characterized by heavy dependence on fossil fuels. Coal and oil accounted for 89.2% of China's total primary energy consumption in 2007 [2]. It means the very small proportion of renewable energy consumption for a long time in China. Consequently, the share of renewable energy consumption, in spite of its rapid growth from 3.4% in 1978 to 9.9% in 2009 (Fig. 1), had a weaker economic performance than that of the dominant conventional energy.

Economic accounting mechanism pitfalls: the environmental accounts, sometimes referred to as "green accounts", are an extension of the national income accounts to incorporate environmental concerns. Pollution represents an external cost because damages associated with it are borne by society as a whole and are not reflected in market transactions. Externalities are defined as benefits or costs generated as an unintended by-product of an economic activity that dot not accrue to the parties involved in the activity and where no compensation takes place. The environmental impacts of fossil fuels often result in real costs to society, in terms of human health (e.g. loss of work days, health care costs), infrastructure decay (e.g. from acid rain), declines in forests and fisheries and, perhaps ultimately, the costs associated with climate change. Although environmental impacts and associated economic costs are often included in economic comparisons between renewable and conventional energy, investors rarely include such environmental costs in the bottom line used to make decisions. If externalities were factored in, some renewable, particularly wind power, would already be cheaper that conventional energy sources.

Policy and institutional barriers: Chinese government has formulated a series of policies on renewable energy development, including laws, regulations, economic encouragement, technical research and development, industrialized support and government renewable energy model projects, etc. These policies play a significant pushing and guiding role in the development and use of renewable energy. However, China's renewable energy development policy begins to show certain disadvantages with rapid growth of economic development and energy demand, these disadvantages include: (1) polices lack coordination and consistence; the coordinative function has not been brought to play; (2) the encouragement policy is inadequate and the system is not complete; government subsidies do not cover enough areas; the subsidies are small and not smooth in their transmission to lower levels; (3) lack of regional policies innovation; comparative advantages and industrialized competitive advantages have yet to be formulated in regional renewable energy; (4) investment and financing system is not healthy and complete; main body of the investment is more than single; (5) currently, China's investment in technical research and development of renewable energy is inadequate, leading some advanced techniques and equipment to severe dependence on importation [56].

For these four reasons a rapid growth in SREC is not accompanied by a similar increase in economic welfare output. On the contrary, the increasing share of REC results in the negatively effects on economic welfare growth. Therefore, from an integrated policy perspective, our analysis highlights that if promoting SREC negatively impacts economic growth, at least initially, governments will need to use complementary policies to achieve environmental and economic welfare goals.

3.5. Marginal effect of REC and SREC

In order to further see the impact differences of REC and SREC on economic welfare. Based on above models of estimation, the Cobb–Douglas production function is also denoted by $Y = f(x) = f(\text{REC, SREC}, K, L, T)$, where Y is a choice variable (economic welfare), x is a vector of explanatory variables (for example

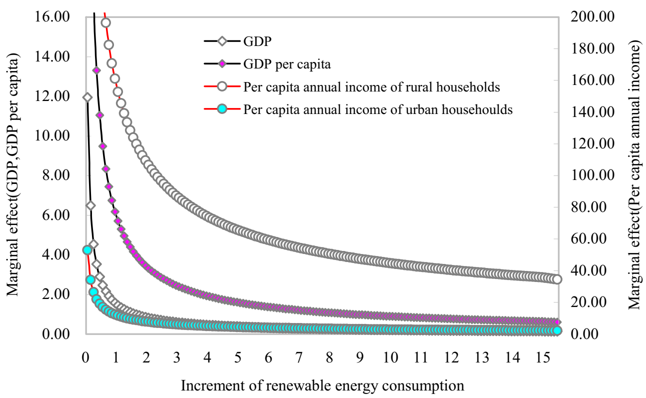

Fig. 4. Marginal effect of renewable energy consumption.

REC, SREC, etc.), then the partial derivative ∂Y/∂(REC) is the rate at which economic welfare changes with respect to the percent changes of renewable energy consumption. We call it the marginal effect (slope) with respect to REC. Likewise, the partial derivative ∂Y/∂(SREC) is the rate of economic welfare change with respect to share of renewable energy consumption and is called the marginal effect of SREC. Marginal effects are commonly used in practice to quantify the effect of variables on an outcome of interest. In these terms, the marginal effect of REC is interpreted as proportional to the amount of economic welfare per unit of renewable energy consumption, and the marginal effect of SREC is also interpreted as proportional to the amount of economic welfare per unit share of renewable energy consumption.

If we put the marginal effects of economic welfare together, we can reach a twofold conclusion: that marginal effects of four economic welfare indicators have been converging (Figs. 4 and 5); and that the speed of convergence seems to be faster in the most initial period of REC or SREC variability. China simple mode shows that marginal effects of economic welfare will be different by different factors that can be interpreted, and there is a negative trend on the marginal effects for nearly all the selected welfare indicators, with the clear exception of per capita annual income for rural and urban households. Figs. 4 and 5 imply that the tendency of the trend parameter is zero, in that regard, given that marginal effect was higher at the beginning of the period, results of equalization by the end of the series would not be surprising. On the one hand, this increases the support that marginal effects of economic welfare are converging to a similar level, in other words, that capital flows, labor force, technological progress, and market or policy integration matter for closing up differentials. On the other hand, in order to alleviate the negative effect of SREC on per capita annual

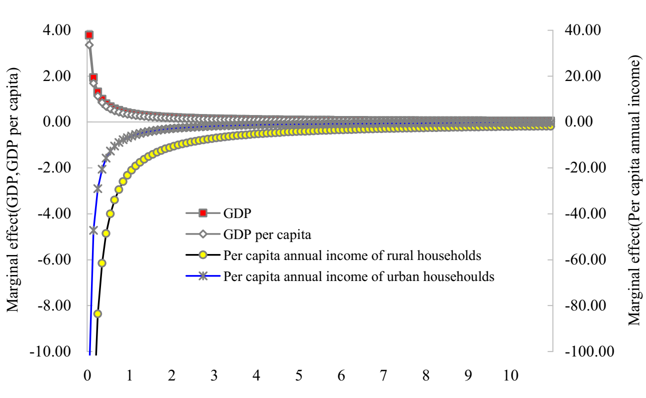

Fig. 5. Marginal effect of renewable energy consumption share.

income for rural and urban households shown schematically in Fig. 5, the goal-oriented policy refinement in increasing share of renewable energy consumption while improvement households income should be addressed efficiently. Hence, the shape of sound and robust renewable energy institutions and policies would matter for increasing the standards of economic welfare, regardless of the national welfare or individual welfare, in the context of speeding up renewable energy development and increasing share of renewable energy consumption.

4. Concluding remarks

In the last decades REC gained an increasing share on the electricity mix of China. On the whole, China sample shows that the high correlation exits between economic welfare variables and renewable energy. Even though increases in per capita annual income of rural and urban households are not closely related with the share of renewable energy consumption increases due to policies and institutional factors.

Research results indicate that a 1% increase in REC increases real GDP by 0.120%, GDP per capita by 0.162%, per capita annual income of rural households by 0.444%, and per capita annual income of urban households by 0.368% respectively.

With respect to scenario of economic welfare impact from the amount of renewable energy consumption, this will include:

- 9.29–15.06% advantage in real GDP, 12.55–20.33% advantage in GDP per capita, 34.39–55.72% advantage in per capita annual income of rural households, and 28.50–46.18% advantage in per capita annual income of urban households respectively in 2020.
- 21.76–37.41% advantage in real GDP, 29.38–50.51% advantage in GDP per capita, 80.53–138.42% advantage in per capita annual income of rural households, and 66.75–114.73% advantage in per capita annual income of urban households respectively in 2030.
- 39.76–72.31% advantage in real GDP, 53.68–97.62% advantage in GDP per capita, 147.13–267.56% advantage in per capita annual income of rural households, and 168.25–221.76% advantage in per capita annual income of urban households respectively in 2050.

The impact of SREC on economic welfare is insignificant. However, the positive effect occurrence of SREC on GDP and GDP per capita even though these effects are very slightly, and an increasing share of REC negatively affects per capita income for rural and urban households. In this paper, possible reasons including the cost, structural demand, accounting mechanism and policy of renewable energy development are stressed.

Marginal effects of renewable energy consumption imply that market openness, institutional innovation, policy integration are important for closing the gap between marginal effects and improvement sustainable development of renewable energy. On the other hand, in order to alleviate the negative effect of SREC on per capita annual income for rural and urban households, the goal-oriented policy refinement should be addressed efficiently in increasing share of renewable energy consumption while improvement households income. Hence, the shape of sound and robust renewable energy institutions and policies would matter for increasing the standards of economic welfare in the context of speeding up renewable energy development and increasing share of renewable energy consumption.

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